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Enhancing Learning Using Multimedia-Interactive Systems: An Experimental Study

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ABSTRACT

The education field is in a process of change driven by new developments in multimedia technology, which is being used as a complementary alternative for teaching purposes. This paper describes a thesis project developed through an exploratory study comparing the effects of using three different teaching approaches: traditional teacher-led instruction, web page instruction and a multimedia-interactive system. The principal objective is to find out whether the use of a prototype multimedia-interactive delivers better outcomes in teaching complex subjects such as data structures, than web page and traditional teacher-led instruction approaches. Information Systems Design Theory was used to develop a multimedia-interactive tool. Students were taught to use binary trees to compare the three teaching methods. Pilot test results show that there are significant differences in performance of students who used the multimedia-interactive tool. It is concluded that the multimedia-interactive system prototype can effectively be used to help students learn binary trees.

Keywords

Multimedia, interactivity, learning, data structures, teaching approaches, Information Systems Design Theory

INTRODUCTION

Educational institutions are adapting their teaching and learning processes to incorporate technological advances (Cabero and Salinas, 2000). Such advances are providing tools. One example are web pages and multimedia-interactive systems, which can be integrated as a new tool used for teaching (Bartolomé, 1998). Previous studies (Jones and Buchanan, 1996) suggest that teacher-led instruction methods are proving ineffective and inefficiencies for the diverse student population. Others studies (Bannan and Milheim, 1996; Parson, 1998; Simbandumwe, 2001) suggest that there has been widespread increase in the level of interest and use by academics of on-line; particularly Web-based instructional systems such as web pages.

Implementing modern information systems and communication technology into teaching lessons enables an entirely new approach for education (Buch, 2002; Kekäle, 2002; Simon, 1999). There are tutorials available and many possibilities for gaining suitable teaching packages and multimedia presentations that are used to teach (Esteruelas, Ezpeleta de la Fuente, Martínez and Moral, 1995).

A multimedia-interactive system is a combination of two elements: multimedia and interactivity. These systems allows users to advance, check and repeat concepts that are presented (Reeve and Sayers, 1996), also to learn complex subjects (Rodríguez, 2000) such as data structures (Brookshear, 1993). Multimedia presents information through of a variety of media, such as music, videos and animation. Interactivity allows users to participate and control information flow, also to decide when and what information is presented (Rodríguez, 2000). There is evidence in previous studies (Bagui, 1998) that in some cases computer-based multimedia can help people to assimilate information better than traditional classroom lectures.

Learning data structures is a complex issue for many students (Hartmann and Hopcroft, 1971; Martí, Ortega and Verdejo, 2003; Peña, 2005). Complexity is defined as a problem that can have several solutions (Rodríguez, 2000). Some complex problems in the computational area are: to teach programming (Kain and Wiedenbeck, 2004), algorithms (Jain, 2005) and data structures (Brookshear, 1993), among others. The major problem in teaching data structures has been the difficulty of capturing the dynamic nature of the material (Karavirta, Korhonen and Stalnacke, 2004).

The subject of learning data structures has been studied under different approaches using different tools (Del Puerto and Ruiz, 2002). Previous studies of teaching data structures are classified based on their interactivity such as tutorials with hypertext (Martí-Oliet and Palomino, 2005; Warendorf, 1997), websites or web pages (Del Puerto and Ruiz, 2002; Pita and Del Vado, 2007) and interactive systems (Karavirta et al., 2004; Park and Hannafin, 1993). Even though the subject of learning data structures has been widely studied under different situations, we did not find evidence that a multimedia-interactive system existed at the moment of conducting our study, specifically designed to teach binary trees. In order to

know whether this technology delivers better outcomes, we expose a group of students to this technology (multimedia-interactive system) in a limited time frame; a second group was taught by a traditional teacher-led instruction and a third group was taught by a web-based instruction.

PILOT STUDY

In order to learn about the phenomena, a pilot study was conducted in the Autonomous University of Aguascalientes (UAA), México using a reduced version of our multimedia-interactive system prototype. This version only teaches binary trees. Three groups composed by twenty students each one participated in this study: one, using traditional instruction methods (TG), other using a web-based approach (WG), and a third group using our multimedia-interactive system (MIG).

Students in their third-semester of a Computer Science bachelor program were invited to participate in the study. At the moment of conducting the study, all participants had taken the basics in programming languages (sequence, decisions, loops, pointers and dynamic memory) and the basics in data structures (arrays and data structures). Participants were randomly assigned to either one of the groups. All groups used the same teaching materials. Contents were focused on the subject of binary trees. This subject was selected because it is identified as a topic that has a high grade to learn of difficulty in previous literature (Martí et al., 2003; Peña, 2005) and has high failure rates of students from the UAA. At the beginning and the end of the session, participants answered a written test so that we learn whether they learn something that they did not know at the beginning of the study.

Description of the Study

As a first step for the pilot study, a measurement instrument was developed. This instrument was evaluated using a group of 30 participants. In order to avoid the effect of stress and anxiety, students were asked to answer a written test, which has no effect in their grades. The measurement instrument consisted of two sections. One section evaluates theoretical concepts of binary trees such as depth, degree and type of operations that can be performed with them. This section had four multiple choice questions. Each question had a one point value. The second section had three exercises: one to demonstrate knowledge on node insertion, another for node deletion, and the last one to search a node in a binary tree. Each exercise had a value of two points. The complete test was to sum up a total maximum score of 10 points. Measurement instrument results are shown in Table 1 as well as Figure 1 shows the histogram. Results show that scores have a normal distribution. Hence, we can argue that our measurement instrument is well designed.

Grade_Test		
N	Valid	30
	Missing	0
	Mean	4.679
	Median	4.727
	Mode	6.5
	Std. Deviation	3.1041
	Skewness	-.088
	Std. Error of Skewness	.427
	Kurtosis	-1.361
	Std. Error of Kurtosis	.833
	Minimum	.0
	Maximum	9.6

Table 1. Pilot Test Descriptive Statistics

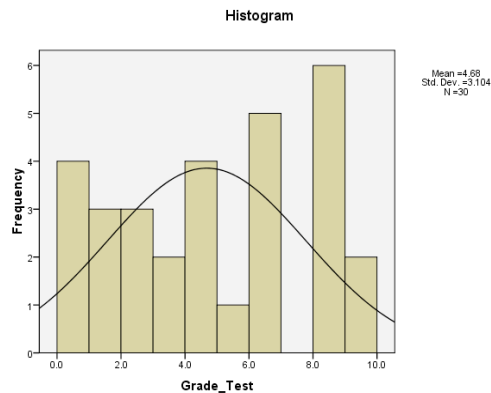


Figure 1. Histogram Grades for the Measurement Instrument

Description of Treatments

In order to control teaching styles differences, each group was taught by the same instructor. Participants received the same lecture, examples and exercises, so teaching materials differences were controlled. In addition, all participants had feedback from the instructor. In order to measure whether participants learn about the subject, the same test was applied before and after the lecture.

Technological differences were controlled by using the same computer laboratory where all computers have the same hardware and software characteristics.. Participants were given free time to study/use the corresponding learning material, also to get answer to any question they might have, they received feedback from the instructor at any time they would require it. Finally, each group had to answer a written test before and after the lesson. Times slots for the pilot study were assigned as follows: study the lesson, 30 minutes; analyze solved examples and exercises, 30 minutes; self-study time, 15 minutes; time to answer questions and feedback, 20 minutes; and finally, time to answer the test 60 minutes. Groups were taught at a different time frame.

Specific Conditions for the Groups

Traditional group (TG) was taught by the instructor using a projector and a PDF file as a learning media. Participants had to solve written exercises by hand. Web page group (WG) was taught by the instructor and he gave the lecture using a projector and a web page as learning media, this group had to solve written exercises. The multimedia-interactive group (MIG) was taught by the instructor using a projector and a multimedia-interactive system as learning media. Participants did solve written exercises through the multimedia-interactive system purposely developed for this study, which was installed in each computer by the duration of the lesson.

Learning Materials for the Groups

The material for the TG was adapted to our Spanish-speaking audience. The PDF file consisted on a simple text with some images as examples (see Figure 2). The instructor had to check and evaluate students' exercises.

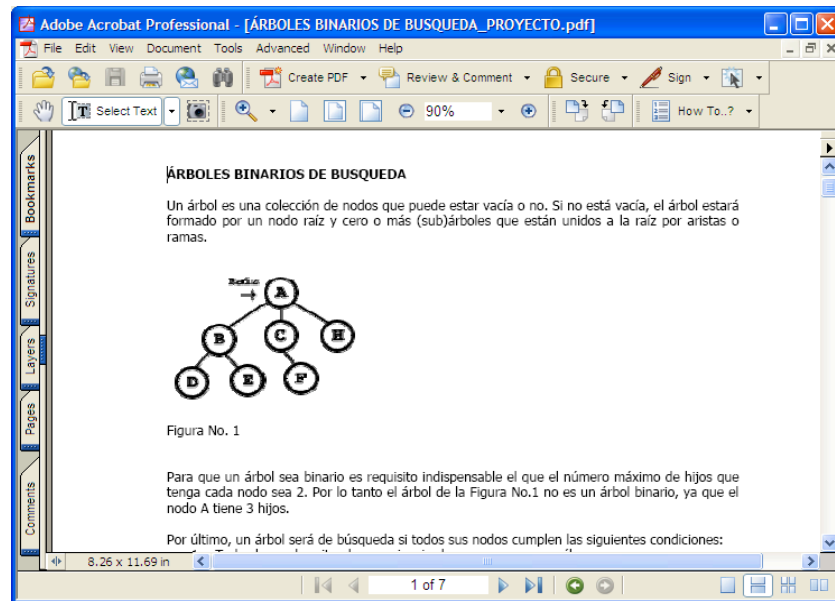


Figure 2. Snapshot of the Learning Material in PDF Format

Figure 3 shows the learning material for the WG. It consisted primarily on text, images as examples, and hyperlinks for easy navigation to go forward and backward through the material as suggested in previous literature (Brodersen, Bourne, Pingree and Shiavi, 2000). An important issue was the absence of multimedia elements (Boyle, 1997; Najjar, 1996). The instructor had to check and evaluate students' exercises.



Figure 3. Snapshot of the Web Page Material

The learning material for the MIG (see Figure 4) consisted on text, images as examples and hyperlinks for navigation purposes (Brodersen et al., 2000). In addition, it has interaction characteristics such as: animation and sounds as well as explanatory sections of each topic (insertion, deletion and searching nodes) (Fulton, Glenn and Valdez, 2004). Moreover, this system includes interactivity: the students had the ability to answer interactive exercises by moving data and images (Bosco,

1986; Fletcher, 1990). Finally, it includes an output section so that participants can see the results of the exercises (Almeida, Blanco and Moreno, 2003; Karavirta et al., 2004). The instructor did not check and evaluate students' exercises. They were evaluated by the tool.

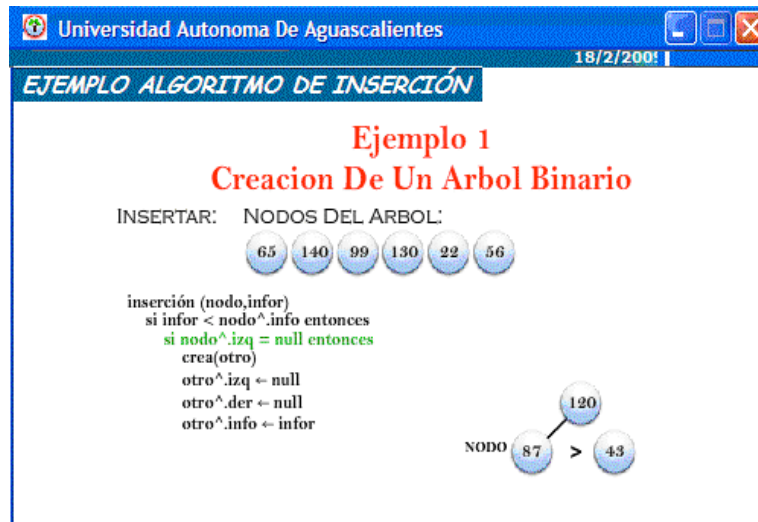


Figure 4. Snapshot of the Multimedia-Interactive System to Teach Binary Trees

FINDINGS

The study was conducted as described before. One test was applied to participants (before and after). Table 2 shows descriptive statistics obtained from test results. Tests were graded using a 0 to 10 scale. TG mean increased an overall 20%. WG mean increased an overall 10%. MIG mean increased an overall 23%. Based on these results, it can be argued that any teaching approach contributed to the overall knowledge. In all groups a reduction in standard deviation can be observed, which means results were less dispersed in the after-lecture test compared to pre-lecture test.

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	BEFORE_TG	4.679	30	3.1041	.5667
	AFTER_TG	6.583	30	1.4025	.2561
Pair 2	BEFORE_WG	5.666	30	2.6238	.4790
	AFTER_WG	6.533	30	1.5365	.2805
Pair 3	BEFORE_MIG	5.001	30	2.7015	.4932
	AFTER_MIG	7.353	30	1.0925	.1995

Table 2. Descriptive Statistics of the Study

In order to test whether groups were similar in knowledge acquired in previous courses, a standard ANOVA test was applied to the pre-lecture test (see Table 3). Results show that there are not significant differences (0.388), which mean that the three groups have similar knowledge and that participants' previous knowledge does not impact our study outcomes.

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	15.210	2	7.605	.958	.388
Within Groups	690.719	87	7.939		
Total	705.929	89			

Table 3. Pre-lecture ANOVA test

In order to test whether teaching approach has an effect in performance, a standard ANOVA test was applied to results from the post-lecture test (see Table 4). Results show that there is a significant difference ($p=.036$) in the performance of the three groups. Hence, teaching approaches do have different outcomes.

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	12.678	2	6.339	3.444	.036
Within Groups	160.123	87	1.840		
Total	172.801	89			

Table 4. Post-lecture ANOVA test

In order to identify which group has better performance, multiple comparisons tests were calculated (LSD and Dunnett tests). Table 5 shows results obtained. In all cases MIG has the highest difference compared to TG and WG (e.g., LSD test: TG vs. MIG, $\text{sig}=.031$). These results support our hypothesis that multimedia technology is a better option in teaching complex subjects such as binary trees.

	(I) Group	(J) Group	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
LSD	Traditional group (TG).	Web page group (WG).	.0500	.3503	.887	-.646	.746
		Multimedia-Interactive group (MIG).	-.7700*	.3503	.031	-1.466	-.074
	Web page group (WG).	Traditional group (TG).	-.0500	.3503	.887	-.746	.646
		Multimedia-Interactive group (MIG).	-.8200*	.3503	.022	-1.516	-.124
	Multimedia-Interactive group (MIG).	Traditional group (TG).	.7700*	.3503	.031	.074	1.466
		Web page group (WG).	.8200*	.3503	.022	.124	1.516
Dunnett t (2-sided) ^a	Traditional group (TG).	Multimedia-Interactive group (MIG).	-.7700	.3503	.056	-1.558	.018
	Web page group (WG).	Multimedia-Interactive group (MIG).	-.8200*	.3503	.040	-1.608	-.032

*The mean difference is significant at the .05 level

a. Dunnett t-test treats one group as control, and compare all other groups against it.

Table 5. Multiple Comparisons After the Study

In conclusion, the pilot study showed that the proposed prototype has merit. Now, we are planning to use a specific methodology such as Information Systems Design Theory (ISDT) (Walls, El Sawy and Widmeyer, 1992) to develop the prototype, which will be tested in order to find out whether the use of a prototype multimedia-interactive constructed using ISDT delivers better outcomes in teaching complex subjects such as data structures, compared to a web-based and traditional teacher-led instruction approaches.

RESEARCH PLAN

Due to the complexity of teaching of data structures, we are designing a multimedia-interactive prototype that supports the teaching-learning process. Therefore, in this study a multimedia-interactive system requires the support of an appropriate information system. An attempt to address this problem we are planning to develop theory-based principles, in the form of an ISDT for a multimedia-interactive system.

ISDT Framework

An Information Systems Design Theory (ISDT) is a methodology proposed by Walls et al. (1992). ISDT's are prescriptive theories that offer theory-based principles developed to provide a guide and solutions to practitioners in the design of Information Systems (IS) (Markus and Majchrzak, 2002). This methodology has the purpose to create artifacts and provide a structural approach to information systems design. The artifact creation relies on kernel theories that are applied, tested and

modified (Markus and Majchrzak, 2002; Walls, El Sawy et al., 1992). Walls et al. (1992) suggested a structure for the ISDT; and it is composed of two elements: the Design Product Components and the Design Process Components (see Table 6).

Design Product Phase	
1. Meta-requirements	Describes the class of goals to which the theory applies
2. Meta-Design	Describes a class of artifacts hypothesized to meet the meta-requirements
3. Kernel theories	Theories from natural or social sciences governing design requirements
4. Testable design product hypotheses	Used to test whether the meta-design satisfies the meta-requirements
Design Process Phase	
1. Design method	A description of procedure(s) for artifact construction
2. Kernel theories	Theories from natural or social sciences governing design process itself
3. Testable design process hypotheses	Used to verify whether the design method results in a artifact which is consistent with the meta-design

Table 6. Components of an ISDT (adapted from (Walls, Widmeyer and El Sawy, 1992))

A design theory is prescriptive and not explanatory or predictive in nature. Walls et al. (1992) believe that the purpose of a design theory is to support the achievement of goals. Thus, a design theory describes how to achieve that goal and not what the goal should be. Finally, an ISDT can be empirically tested and, as any theory, serve as the starting point for new research. In order to develop an ISDT for a multimedia-interactive prototype is important to follow three steps (Figure 5):

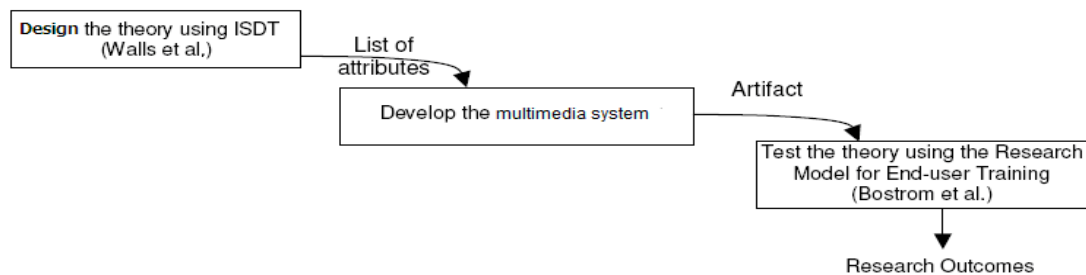


Figure 5. Training Research Process Model (Adapted from (Gomez, Olfman, Ryan and Horan, 2005))

Design the software training tool

The main requirements for our study are the development of an instructional material to be taught in the classroom in a traditional teaching approach, a web system and a multimedia-interactive system. Contents and software-based systems interfaces will be adapted to our Spanish speaking audience.

Traditional instruction material will be in PDF format and will consist of text and images. Web page interface will be on html format. This tool will follow previous literature recommendations some images as examples and hyperlinks for navigation to go forward and backward through the material (Brodersen et al., 2000), the absence of multimedia elements (Boyle, 1997; Najjar, 1996) as well as will show information about the topic in a text format.

Our multimedia-interactive tool will have the same contents of the PDF file and the web system (text and images that shows the general information about the topic), include some interaction differences such as animation and sounds as explanatory sections of each topic (insertion, deletion and searching nodes) (Fulton et al., 2004) and interactivity sections (Bosco, 1986; Fletcher, 1990). Finally, an output section to show exercises' results to students (Almeida et al., 2003; Karavirta et al., 2004). ISDT is being used to identify the meta-requirements for our multimedia-interactive system so that it can be developed to maximize learning.

Based on results from the pilot test, currently, we are developing our ISDT. As a first step we are planning to complete the ISDT, enhancing the kernel theories, features and requirements. After that, we will develop our multimedia-interactive system and test at least two different prototypes of it for quality and usability purposes. Finally, we will apply an exploratory study using three groups: traditional led instruction, web-based instruction and our multimedia-interactive system.

Test the training tool.

In order to evaluate which training tool delivers better outcomes, we are planning to test the training tools in a laboratory experiment, in the Autonomous University of Aguascalientes (UAA), México. We will use three different groups; each one will use a different teaching approach. Participants will be randomly assigned to each group. One instructor will teach the lectures in all groups using the corresponding training tool. Before and after the experiment, we will apply a written test to identify the effects of each type of teaching approach. After that, we will analyze results and draw the conclusions of this proposed research.

AN ISDT FOR A MULTIMEDIA-INTERACTIVE SYSTEM

A multimedia-interactive system involves teaching and learning tasks associated with information distribution, communication, and student assessment; also it requires a high level of expertise from a number of different fields such as content matter, technology, management and instructional design (Jones and McCormack, 1997). This section introduces our ISDT for a multimedia-interactive system by describing the design product phase as explicated by Walls et al. (1992) including: requirements, design practices, kernel theories and hypotheses (see Table 7).

1. Meta-requirements	<p>Interactive dimension (identify sources of mistakes, design informative tutoring feedback, design tutoring instructions).</p> <p>Cognitive dimension (define learning objectives in terms of concrete learning outcomes, identify knowledge elements by analyzing and structuring the subject matter, select and specify cognitive operations that have to be mastered).</p> <p>Formal dimension (compose item, select and specify form and mode of presentation).</p> <p>Framework of training.</p> <p>Graphical user interface to retrieve and build examples and exercises.</p> <p>Examples and exercises.</p>
2. Meta-Design	<p>Concepts of problem solving, software engineering and cognitive aspects.</p> <p>Interactivity and feedback.</p> <p>Hypermedia templates, design patterns and interface design.</p>
3. Kernel theories	<p>Framework for research on end-user training (Bostrom and Olfman, 1990).</p> <p>User interface design (Alfaro and Henzinger, 2001; Henderson, 1991).</p> <p>Hypermedia templates (Catlin and Garret, 1991).</p> <p>Design patterns (Catlin and Garret, 1991; Rossi, Schwabe and Garrido, 1997).</p> <p>Problem solving (Newell and Simon, 1972).</p> <p>Software engineering methods (Salcedo, 2000).</p>
4. Testable design product hypotheses	<p>It is possible to construct an Information System for a multimedia-interactive tool specifically designed to teach binary trees that delivers better outcomes than using traditional teacher-led instruction and web page approaches.</p>

Table 7. Design Product Phase (Adapted from (Walls, Widmeyer et al., 1992))

Brief Description of Kernel Theories

1. Framework for research on end-user training (Bostrom and Olfman, 1990). Models and approaches for conducting research on the training initiatives in organizations and how they apply them.
2. User interface design (Alfaro and Henzinger, 2001; Henderson, 1991). This theory is important for several reasons. First of all the more intuitive the user interface the easier it is to use, and the easier it is to use and the less expensive to use it. The better the user interface the easier it is to train people to use it, reducing your training costs. The better your user interface the less help people will need to use it, reducing your support costs. The better your user interface the more your users will like to use it, increasing their satisfaction with the work that you have done.

3. Hypermedia templates (Catlin and Garret, 1991). These are an approach to simplify the authoring process while still ensuring the application of good information design principles. Experts, with appropriate skills, are responsible for the creation of hypermedia templates. Templates enable and simplify the capture and reuse of design problem.
4. Design patterns (Catlin and Garret, 1991; Rossi et al., 1997). Design patterns offer an approach to documenting and supporting the reuse of design. The use of patterns provide benefits such as solving a particular problem that can be tailored to specific cases making it easier, enable choice between alternatives, and improve the documentation and maintenance of existing systems.
5. Problem solving (Newell and Simon, 1972). It is focuses on how humans respond when they are confronted with unfamiliar tasks. Is seldom a purely mental activity, but rather interleaves reasoning with execution. Eager execution of partial plans can lead the problem solver into physical dead ends that require restarting the task. Learning from successful solutions transforms backward chaining search into informed skill execution.
6. Software engineering methods (Salcedo, 2000). Aims to examine some specific processes required for the production of high quality software, for example, methods for testing software, ensuring reliability or performance in software.

CONCLUSION

The expected outcomes of the study and the principal contribution is to develop an ISDT for a multimedia-interactive system that offers a greater variety of features in the teaching and learning process, as well as to provide a guide to students and professors. Instructors might get a clearer idea about what circumstances this type of systems can be more effective to improve academic performance.

It is necessary to have special attention on participant's motivation. End-user participation in the development of our multimedia tool might enhance the chances of end-user acceptance so that outcomes can be improved.

It is important that all instructional material have the same design in order to have the certain about the performance of each instructional material. Having exactly the same design in all tools we can argue that multimedia does improve performance.

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